Correlation Analyses of 500 mb Heights in the Northern Hemisphere from a View-Point of Seasonal Forecasting for North Japan

—On Factors Governing the Summer Temperature of North Japan—

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Abstract

Correlation coefficients between the monthly mean temperature of Sapporo in July and 500 mb heights in preceding months have been investigated. The 500 mb heights used in this work are read off from the monthly mean charts of previous November, January, March and May for the period from 1946 to 1960 at 99 mesh points.

As a result of screening calculation, high correlations to the temperature of Sapporo have been found on the 500 mb chart for previous November in the vicinity of the Caspian Sea and for January in the south of the Lake Baikal with correlation coefficients of $+0.74$ and $+0.72$ respectively. While, in March and May, correlations are not so high as in November or January. A multiple correlation coefficient between the July temperature and the 500 mb heights at the center of these high correlations in November and January is 0.87 . This suggests that the temperature in July over North Japan is governed statistically by the behaviour of the general circulation of previous November and January.

Furthermore, the following two relations have also been discovered. One is that the 500 mb height in November over the Caspian Sea is related to the formation of the Okhotsk Sea High in the following July. The other is that the 500 mb height in January in the south of the Lake Baikal is related to the anticyclone of the middle latitude over the Northwest Pacific in July.

1. Introduction

Recently, public demand for seasonal weather forecasting has increased. Especially, the forecasting for summer season is required ardently in view of the fact that the summer temperature in North Japan differs considerably among individual years. Methods of seasonal forecasting now in use are, however, still in the stage of "Empirical Science", and of course the law of causality between the summer temperature and many foreshadowing phenomena which have been found so far has little physical foundation. Research workers of numerical prediction are evaluating various meteorological elements quantitatively for analyzing the general circulation of the atmosphere, but the results obtained are not in the stage of direct application to long-range fore-

cast routine.

In this respect, it may be advisable to use meteorological elements at a time and at a point as the fundamental materials for predicting the circulation patterns half a year ahead. As our purpose is the statistical prediction of weather over certain time period and certain area, it will be legitimate to use the mean value of each meteorological element taken over suitable time period and suitable area. Theoretically it may be advisable to choose such a time period and an area that would give the largest probability representing the degree of expectation of the situation in prediction.

Now, let us consider two parameters X and Y which are highly correlated with each other, and average them as follows:

$$\bar{X}(P, S) = \frac{1}{PS} \int_P \int_S X dP dS \quad (1)$$

$$\bar{Y}(P', S') = \frac{1}{P'S'} \int_{P'} \int_{S'} Y dP' dS' \quad (2)$$

where P is a time period of averaging X , and S is a spread of area of averaging X ; P' and S' are the similar quantities. Then, the correlation coefficient between $\bar{X}$ and $\bar{Y}$, noted as R , is a function of P, S, P' and S' , viz.,

$$R = f\{X(P, S), Y(P', S')\} \quad (3)$$

For suitable values of P, S, P' and S' noted as P_c, S_c, P'_c and S'_c , the R will take the largest value. Then, the mean value of meteorological elements such as $\bar{X}(P_c, S_c)$ and $\bar{Y}(P'_c, S'_c)$ shall be called the “ U -element”, and the relation between $\bar{X}(P_c, S_c)$ and $\bar{Y}(P'_c, S'_c)$ shall be called the “ C -operation” in the present paper.

Combining these C -operations, we are able to see the annual variation or the causality of the general circulation of the atmosphere with an eye of statistical probability.

The purpose of the present study is to show that this statistical securing contributes to physical prediction of the *Grosswetterlage*. In this report, the correlation between the temperature of Sapporo, the capital of Hokkaido in Japan, in July and 500 mb heights of the Northern Hemisphere for the period from previous early winter to midspring is investigated.

2. Method of investigation and data

The establishment of U -element, which requires enormous amount of work, is an important study by itself. The workers of Multanovski school [1] treat the concept of U -element, and propose the notions of the “natural synoptic period”, and the “natural synoptic district”. Then, it is to be desired that there exists a good relation between the concept of U -element and that of Multanovski school. And the author thinks that the concept of “step by step variation of season” proposed by H. Matsukura [2] and developed by K. Kimura, who treats this concept by making use of the equivalent temperature of Asahikawa, Hokkaido in Japan, must be applied to this study of U -element.

Let us suppose hereafter that U -elements

consist of monthly mean value of meteorological elements at a single station and monthly mean 500 mb heights of one mesh point. The author calls the above U -element a “virtual U -element”. And it is good that C -operation with high correlation calculated from virtual U -element should be corrected by the natural U -element which will be calculated later. On the other hand, the author confirms that new factors governing the U -element may be discovered by the C -operation calculated from virtual U -element.

Fig. 1. Distribution of mesh points where correlation coefficients are calculated.

In this report “monthly mean value” is the mean value of six 5-day means, excepting for August where seven 5-day means constitute the monthly mean. And monthly mean 500 mb heights over the Northern Hemisphere used in this work are calculated from “the tables of 5-day mean heights on the Northern Hemisphere”, published by Japan Meteorological Agency, for 14 years from 1946 to 1959 and a part of 1960. Mesh points at which the correlation is calculated are 99 in number and their locations are shown in Fig. 1. The points No. 91~No. 93, No. 103~No. 108 are not used for lack of data.

Correlation coefficients are calculated by the ordinary formula. In this manner, calculating coefficients between certain meteorological element and 500 mb height at each mesh point and drawing isoline of coefficients on a map, we get the geographical distribution of the correlation coefficients which we shall call hereafter a "correlation pattern". The results are shown in the next paragraph.

Fig. 2. Confidence limits of correlation coefficient of sample. This figure is cases of $n=14$ with two significant levels, 0.15866 and 0.02275 (after M. Ogawara).

However, the number of samples, noted as n , is 14 which may not be sufficient to this investigation. Therefore the goodness of these correlation coefficients is tested by the method of M. Ogawara [3]. The case for $n=14$ with two significant levels $\alpha=0.15866$ and $\alpha=0.02275$ is drawn off from his result, and shown in Fig. 2. Here, the abscissa is the absolute value of correlation coefficient of sample which is noted as $|r|$, and the ordinate ρ is that of population corresponding to r .

When $\alpha=0.02275$, the value ρ corresponding to $r=0.2$ may be in the interval from the upper limit $+0.6$ to the lower one -0.4 , and admitting $\alpha=0.15866$ the lower limit of ρ is still in the critical region. That is, the sample coefficient $r=0.2$ must be rejected with $\alpha=0.1$. This value $\alpha=0.1$, shall be admitted in this study. Let us look the $r=0.4$. With $\alpha=0.02275$ the lower limit of ρ is even in the critical region, but with 0.15866 the ρ is out

of this region. Considering these estimations, it is confirmed that a coefficient of sample, the value of which is ≥ 0.4 , is significant with a level of $\alpha=0.1$ to say the least of it. And also, from another calculation [4] it is known that $r \geq 0.45$ is significant with $\alpha=0.05$, and $r \geq 0.63$ with $\alpha=0.01$.

In the correlation pattern in the next paragraph, areas with coefficients larger than 0.4 are shaded considering the significance of correlation.

3. Correlation pattern affecting the temperature of Sapporo in July

Now, let us use the following notations to simplify the description.

$T_{S, Jul}$: monthly mean temperature of July at Sapporo

H_{Nov} : monthly mean 500 mb heights of November at all 99 mesh points over the Northern Hemisphere

$H_{42, Jan}$: monthly mean 500 mb height of January at the mesh point No. 42

In order to forecast $T_{S, Jul}$ statistically, we have to know about the simultaneous relation-

Fig. 3. Simultaneous correlation pattern of monthly mean July 500 mb height for monthly mean July temperature of Sapporo.

ship between $T_{S, Jul}$ and H_{Jul} . Fig. 3 is the correlation pattern of H_{Jul} for $T_{S, Jul}$. It is not inconsistent with our experience that there is positive high correlation $+0.8$ over the coast of Sanriku, the Pacific side of Northern Honshu in Japan, and negative one -0.7 over Kamchatka. It also seems that the negative one -0.6 in the east off Formosa is related to frequent appearance of typhoons. On the other hand, it is often seen that high positive temperature at Sapporo is associated with 500 mb anomaly centers in several parts of the Northern Hemisphere. This experience is supported by the existence of correlation centers with coefficients $+0.6$ over North Europe, -0.6 in the vicinity of the Hudson Bay and -0.7 over California.

However, such distribution of positive and negative areas in the correlation field should not be regarded as the distribution of 500 mb height anomaly. Correlation pattern represents the distribution of these coefficients but it is not related directly to anomaly pattern of 500 mb heights.

Now, let us study the correlation between $T_{S, Jul}$ and 500 mb heights of previous months

Fig. 4(b). Correlation pattern of monthly mean July 500 mb heights for monthly mean previous Nov. 500 mb height of the mesh point No. 39 ($50^{\circ}N$, $50^{\circ}E$).

Fig. 4(a). Correlation pattern of monthly mean Nov. 500 mb heights for monthly mean following July temperature of Sapporo.

for seeking good foreshadowing phenomena for the summer temperature of North Japan.

(1) Case of November

Fig. 4(a) is the correlation pattern of H_{Nov} for $T_{S, Jul}$. In this figure, there is a good correlation $r > +0.7$ to the north of the Caspian Sea with an annexed negative correlation -0.6 over the north coast of the Arabian Sea, and -0.5 over British Isles. And elsewhere we see scarcely any considerable correlation except -0.6 on the Gulf of Mexico.

As the value over the Caspian Sea is dominant in the Northern Hemisphere, correlations between $H_{39, Nov}$, located at $50^{\circ}N$, $50^{\circ}E$, and H_{Jul} have been calculated for the purpose of predicting 500 mb pattern of following July. Fig. 4(b) is a calculated result for it. In this figure, two high and negative correlations, more than -0.7 , are situated as a pair. One is over the north coast of the Okhotsk Sea, and the other is extending from the northwest part of Greenland to Canadian Arctics. A zonal positive pattern $+0.6$ extends across Japan Islands, and also an area of $+0.6$ is located over the sea off east of American Con-

continent. This phenomenon provides useful inference for seasonal forecasting of the east districts of Canada and the U.S.A..

Comparing Fig. 4(b) with Fig. 3, it is seen that the both patterns are similar so far as the general situation is concerned, although small differences exist between them.

From the distribution of the correlation it is presumed that the situation of 500 mb height of November over the northern district of the Caspian Sea would govern the behaviour of 500 mb height of the following July over the north district of the Okhotsk Sea and that of Canadian Arctics. It is also considered that positive correlation $+0.6$ over Japan Island and another one on the sea off east of the American Continent are the annexing phenomena with the above-mentioned two negative correlations, respectively.

(2) Case of January

Fig. 5(a) is the correlation pattern of H_{Jan} for $T_{S, Jul}$. An area of high correlation is situated over Chinese Continent with two centers of $r > +0.7$; one is to the south of the Lake Baikal, the other is in the vicinity of Tibetan Plateau, being dominant in this cor-

Fig. 5(a). Correlation pattern of Jan. 500 mb heights for July temperature of Sapporo in same year. Same as Fig. 4(a).

Fig. 5(b). Correlation pattern of July 500 mb heights for Jan. 500 mb height of the No. 42 (50°N , 110°E). Same as Fig. 4(b).

relation pattern. And a positive one, $+0.6$, is located over the north coast of Africa and a negative one, -0.6 , is over the inner part of American Continent. Therefore, let us calculate the correlation pattern of H_{Jul} for $H_{42, Jan}$ which is located to the south of the Lake Baikal, 50°N , 110°E , in the same way as for November. The result is shown in Fig. 5(b). Comparing this with Fig. 4(b), we find that the general feature of the correlation pattern is analogous to that of November except the following phenomena. Negative correlations over the north coast of the Okhotsk Sea and over Canada are weaker as compared with those of November and both have the value of -0.6 . And also, a negative correlation over Mexico is emphasized. Contrary to these, a positive correlation over Japan Islands has more increased than that of November, and its value is more than $+0.7$. In addition to this, the feature of the middle latitude in the Pacific, where the correlation was low in November, has systematised to positive correlation though its value is only $+0.4$.

Considering these relations, it seems that situation of 500 mb height in January over the

Fig. 6(a). Correlation pattern of Mar. 500 mb heights for July temperature of Sapporo. Same as Fig. 4(a).

Fig. 7(a). Correlation pattern of May 500 mb heights for July temperature of Murooran. Same as Fig. 4(a).

Fig. 6(b). Correlation pattern of July 500 mb heights for Mar. 500 mb height of the No. 36 (60°N, 20°W). Same as Fig. 4(b).

Fig. 7(b). Correlation pattern of July 500 mb heights for May 500 mb height of the No. 44 (50°N, 150°E). Same as Fig. 4(b).

south of the Lake Baikal would govern behaviour of middle latitude of the Pacific of the following July.

(3) Case of March

Fig. 6(a) is a correlation pattern of H_{Mar} for $T_{\text{S, Jul}}$. Comparing this figure with those of November and January, it is found that correlation of March is inferior to those latter cases, excepting only one significant correlation center, located in the vicinity of Iceland with +0.6.

Therefore, the mesh point No. 36, located south of Iceland, 60°N , 20°W , was picked up as a key point. Fig. 6(b) is the correlation pattern H_{Jul} for $H_{36, \text{Mar}}$. In this figure, areas of high correlation are scattered here and there. At the same time the correlations are smaller than in the cases of November and January. There are only two correlation centers with the coefficient +0.6, which are useful in this pattern, one is over the East Pacific and the other is over the eastern part of the American Continent.

(4) Case of May

Fig. 7(a) is a correlation pattern of H_{May} for T_{Murooran} . Here, the reason why Murooran was chosen as a key station is as follows.

According to the investigation by T. Segawa [5], there are negative high correlations between the monthly mean wind velocity of May at Mt. Fuji in Japan and monthly mean temperature of July over North Japan, especially in the districts faced to the Pacific. Namely, the coefficients computed for Obihiro and Murooran in Hokkaido, and Miyako in Northern Honshu are all negative and higher than -0.7.

In Fig. 7(a), the high correlation +0.7 located in the central part of the Okhotsk Sea means that the preeminence of blocking high of the Okhotsk Sea in May would bring us warm July in Hokkaido. However, considering the fact that this high correlation is located in such high latitude as 50°N , it seems that the intensity of this blocking high must be too moderate to reach Arctics.

Now, the mesh point No. 44 is chosen as a key point. Fig. 7(b) is the correlation pattern of H_{Jul} for $H_{44, \text{May}}$. In this figure we find a positive correlation +0.6 over Japan Island and in the Central Pacific, and a negative correlation -0.6 on Central Asia and over the Hudson Bay. And also, the general feature of this

correlation is better than the case of March, but does not reach the level of November or January.

4. Test for the seasonal forecasting of North Japan

In the foregoing paragraphs, it is shown that there exist predominant correlation to $T_{\text{S, Jul}}$ in the monthly mean 500 mb pattern of previous November and that of January. Now, the scatter diagram between $H_{39, \text{Nov}}$ and $T_{\text{S, Jul}}$ is shown in Fig. 8(a). The plotted points are divided into two groups, one belonging to the straight line *A*, the other to the bend line *B*. And the points belonging to the straight line *A* are indicated by black circles and those of the bend line *B* by white ones. The number attached to each point is the calendar year.

In order to discriminate the points belonging to the straight line *A* from those belonging to the bend line *B*, the relation between $H_{39, \text{Nov}}$ and $H_{42, \text{Jan}}$ is examined, and the result is shown in Fig. 8(b). As can be seen from this, these points are divided into four groups, namely *W*, *C*, M_n , and M_j . And it is found that points plotted within *W* or *C* domain belong to the straight line *A*, and those within M_n or M_j domain to the bend line *B*.

And it is considered that the situation of November and January plotted in *W* domain corresponds to warm July with a weak anticyclone over the Okhotsk Sea and a dominant Ogasawara High which is the western tail of the middle latitude anticyclone of the North Pacific. And the situation in *C* domain corresponds to the reverse one. In the case of M_n domain, there will be moderate summer with a weak Okhotsk Sea High and an inferior Ogasawara High, but in that of M_j , we shall have a summer of complex character with a powerful Okhotsk Sea High and a dominant Ogasawara High.

Then, we are able to predict a monthly mean July temperature of Sapporo from the situation of 500 mb of previous November and January admitting an error of $\pm 0.5^\circ\text{C}$.

Next, let us calculate a multiple correlation coefficient of $H_{39, \text{Nov}}$ and $H_{42, \text{Jan}}$ for $T_{\text{S, Jul}}$. The basic data for the calculation are given in Table 1, where x is $T_{\text{S, Jul}}$, y is the corresponding $H_{39, \text{Nov}}$ and z is the $H_{42, \text{Jan}}$. Calculu-

Fig. 8. (a). Relation between monthly mean Nov. 500 mb height of the No. 39 and following July temp. of Sapporo. (b). Scatter diagram between Nov. 500 mb height of the No. 39 and that of Jan. of the point No. 42. Considering Fig 8(a), the diagram is divided into 4 areas.

Fig. 9. Relation between observed monthly mean July temperature of Sapporo and values calculated by multiple correlation method.

lating from Table 1, we obtained the following values:

$$r_{xy} = +0.74$$

$$r_{yz} = +0.38$$

$$r_{xz} = +0.71$$

$$R_{x-y,z} = 0.87 \quad (n=14)$$

where $R_{x-y,z}$ is the multiple correlation coefficient. Then the net regression is

Table 1. Data of high correlation points and calculated results.

	Nov: 500 mb height at No. 39 (50°N, 50°E)	Jan: 500 mb height at No. 42 (50°N, 110°E)	July: Observed temperature at Sapporo	July: calculated temperature at Sapporo
	y	z	x	
1947	570	244	20.1	19.7
1948	563	334	21.7	21.4
1949	504	342	20.2	20.8
1950	623	315	22.5	21.9
1951	572	290	19.5	20.7
1952	546	257	20.4	19.7
1953	606	292	19.7	21.2
1954	457	249	17.8	18.3
1955	633	340	23.5	22.5
1956	469	214	18.0	17.8
1957	422	282	19.4	18.5
1958	490	309	19.8	20.0
1959	549	285	20.0	20.3
1960	564	255	20.0	19.9
mean	540.6	286.3	20.19	
$n\sigma$	858.8	528.0	20.73	

$$x = 0.01327y + 0.01968z + 7.38 \quad (4)$$

Let us test the goodness of $R_{x,y,z} = 0.87$ by hypothesis of F -distribution. In this sample n_1 is 2, and n_2 is 11, then

$$F_0 = \frac{R_{x,y,z}^2}{1 - R_{x,y,z}^2} \frac{n_2}{n_1} = 17.12 \quad (5)$$

and for a value 0.5% as a level of significance

$$P_r\{F > 8.9122\} = 0.5\% \quad (n_1 = 2, n_2 = 11) \quad (6)$$

So that, from a view-point of statistics, the value 0.87 of $R_{x,y,z}$ is strictly significant with the significance level of 0.5%.

Now, July temperature of Sapporo calculated by eq. (4) is shown in the last column of Table 1. Fig. 9 is the scatter diagram between the calculated values and observed temperatures. Comparing this with Fig. 8(a), it can be said that if the straight line *A* and the bend line *B* should exist really in any epoch before or after the present one, Fig. 8(a) would give more accurate prediction of July temperature of Sapporo than Fig. 9. Furthermore, it may be seen that the error in Fig. 8(a) is $\pm 0.5^\circ\text{C}$ and that of Fig. 9 is $\pm 1.0^\circ\text{C}$.

But, in the year of 1961, the relation of Fig. 8(a) and Fig. 8(b) failed in prediction as can be seen from the position of crosses in these figures; viz, the point located in M_n domain of Fig. 8(b) deviated from the bend line *B* and came to the straight line *A* in Fig. 8(a). Gathering these facts, it is safe for the prediction to use Fig. 9; as can be seen in this forecasted point indicated by the cross lies fairly close to the regression line.

5. Discussions

How well the correlation obtained from the data for these 14 years fit for the climatic change before this epoch? It has been pointed out by T. Yamamoto [6] that cold winters with much precipitation in Honshu area bring us warm summer with less rain in Central Japan. In consideration of this, it may be said

Fig. 10. The schematical indication of the correlation relationships.

that the positive correlation between H_{42} , Jan and $T_{S, Jul}$ has persisted firmly though there are some epochs where the correlation weakened. However this study must be carried on powerfully from a view-point of climatic change.

A schematical indication of the above-mentioned correlation is shown in Fig. 10. Why is it that the phenomena in early spring do not appear so significant as those of November or January? Examining these phenomena, the author presumes that there are two factors governing the warmth of July over North Japan. One is the behaviour of the prewinter circulation and the other is the circulation in midspring. The former would be owing to the characteristics of the growing stage of the polar night jet stream, and the latter would depend on characteristics of the stratospheric summer circulation. On this problem, discussion will be made in the following report.

In this paper, the final predictand for screening of the correlation phenomena is the monthly mean July temperature of Sapporo. For the analysis of natural phenomena, it is not a good method to choose such element of existing station as the final predictand. And then, final predictands must be certain elements of particular districts which characterize the general circulation of each season such as action centers. The author calls it a "natural station". In the second report, this natural station shall

be investigated.

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北日本の季節予報からみた 500 mb 高度の相関解析

—北日本の夏を規制する因子について—

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札幌の7月々平均気温と前年11月, 同年1月, 3月, 5月の北半球99格子点の月平均500 mb高度との間の相関係数が, 1946年から1960年までの資料で計算された。その結果, 11月のカスピ海北部の高度との間に+0.74, 1月のバイカル湖南方の高度との間に+0.72の相関がある。その後, 3月の相関はこれらに比べるとかなり悪くなっているが, 5月にはカムチャツカからシベリヤ東部にかけて+0.6以上の正相関域が現われている。また札幌7月気温に対する上記11月と1月の重相関係数は+0.87となっており, 7月の北日本気温は前年11月とその年の1月の北半球の循環の状態から確率的に規制されているといえよう。

また, 11月のカスピ海の近傍の高度は7月のオホーツク海高気圧に, 1月のバイカル湖南方の高度は7月の北太平洋中緯度高圧帯に関連していることを暗示する高相関が組織的に現われている。